Cutting Inserts Wear Monitoring in AISI 1045 Dry Longitudinal Turning through Cutting Forces: a Case Study

ASM MS&T 2019 – October, 2019 – Portland, OR

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Industrial Context

- High industrial financial stakes
- Example: Oil industry pipe threading
  - 100 000€/month cutting inserts for one machine-tool
  - Cutting insert end-of-life:
    - Operator's hearing
    - (Unaided) visual cutting insert observation
    - Mirror finish of the thread
    - Tolerance: 5-10 µm
  - 1-2 % scrap

- Is it possible to save on cutting inserts without worsening the scrap rate?
Cutting tools degradation

- Flank wear
  - Most predictable [1, 2]
  - Most advisable [1, 2]
  - Mainly due to abrasion [1, 2]
    - End-of-life criterion [3]:
      - VB=0.3 mm (mean)
      - VB=0.6 mm (max)
  - Specific to life-testing
  - Industrial practice differs

Cutting tools degradation

- Degradation modeling
  - Tool life models (Taylor’s model) [1]
  - Description of degradation trajectory [2]
  - Degradation models
    - Archard [3]
    - Takeyama and Murata [4]
    - Usui [5]

Arrhenius laws

Degradation monitoring

- Condition monitoring
  - Vibratory frequential contents below 10 kHz (RMS) [1]
  - Noise (change in pitch) [2]
  - Cutting forces (RMS, $F_f/F_c$ ratio) [3]
  - Tool temperature [4]
  - Quality (roughness, dimensional deviation) [5]

Degradation monitoring

- Condition monitoring
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Experimental Setting

- Workpiece: cylindrical bars
  - AISI 1045 (154 HV$_{30}$)
  - 250 mm length, 58 mm diameter, 10 passes with $a_p = 0.7$ mm
  - Wear, Forces and roughness measurements every 10 passes
Tool Wear

Before

30 min dry turning
Tool Wear

Comparison between a worn and a new insert
Planar cuts of the cutting edge -- Insert inclined by 45°

Flank wear
Crater wear
Cutting Forces Measurement

- Cutting, feed and radial force
  - Triaxial Kistler 9257B force sensor
  - Sensitivity: -7.5 pC/N ($F_f$ and $F_r$); -3.7 pC/N ($F_c$)
  - RMS values over the pass
**Cutting, Feed and Radial Force**

- Increases of resp. 9%, 40% and 10%
- Locally important increase prior to tool end-of-life

### Correlation vs. $V_{B,\text{mean}}$

<table>
<thead>
<tr>
<th></th>
<th>Pearson correlation coefficient</th>
<th>95% confidence interval</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{B,\text{mean}}$ vs $F_c$</td>
<td>0.81</td>
<td>[0.47, 0.94]</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>$V_{B,\text{mean}}$ vs $F_f$</td>
<td>0.87</td>
<td>[0.63, 0.96]</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>$V_{B,\text{mean}}$ vs $F_r$</td>
<td>0.51</td>
<td>[-0.05, 0.83]</td>
<td>0.07</td>
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### Correlation vs. $V_{B,\text{max}}$

<table>
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<tr>
<td>$V_{B,\text{max}}$ vs $F_c$</td>
<td>0.88</td>
<td>[0.63, 0.96]</td>
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</tr>
<tr>
<td>$V_{B,\text{max}}$ vs $F_f$</td>
<td>0.93</td>
<td>[0.78, 0.98]</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>$V_{B,\text{max}}$ vs $F_r$</td>
<td>0.48</td>
<td>[-0.10, 0.81]</td>
<td>0.10</td>
</tr>
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</table>
Force ratio $\frac{F_f}{F_c}$ and Tool Wear

- Major indicator of tool wear in literature
- 29% increase
- Locally important increase prior to tool end-of-life

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<tr>
<th>Correlation vs. $V_{B,mean}$ and $V_{B,max}$</th>
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<tbody>
<tr>
<td>$V_{B,mean}$ vs $F_f/F_c$</td>
<td>0.86</td>
<td>[0.59, 0.96]</td>
<td>&lt; 0.001</td>
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<tr>
<td>$V_{B,max}$ vs $F_f/F_c$</td>
<td>0.90</td>
<td>[0.69, 0.97]</td>
<td>&lt; 0.001</td>
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Roughness Measurement

- Total, arithmetic and quadratic roughness
  - $R_t =$ total height of the profile
  - $R_a =$ arithmetic average roughness
  - $R_q =$ quadratic average roughness

- Diavite DH-6 roughometer
- 3 longitudinal measurements on each bar, separated by 120°
- Gaussian filter in accordance with ISO 16610
Roughness and Tool Wear

- Total, arithmetic and quadratic roughness
  - Increases of resp. 75, 47 and 64 %
  - Indicator may be considered
    - Not monotonous evolution
    - Not on-line measurement
  - Locally important increase at tool end-of-life
Roughness and Tool Wear

- Arithmetic roughness as an indicator of tool wear
- $p=0.95$, CI95 is $[0.86, 0.98] \rightarrow$ very strong correlation
- $p<0.001 \rightarrow$ significant

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<td>$V_{B_B}$ vs $R_a$</td>
<td>0.95</td>
<td>[0.86, 0.98]</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>$V_{B_B}$ vs $R_t$</td>
<td>0.62</td>
<td>[0.17, 0.85]</td>
<td>0.011</td>
</tr>
<tr>
<td>$V_{B_B}$ vs $R_q$</td>
<td>0.90</td>
<td>[0.72, 0.96]</td>
<td>&lt; 0.001</td>
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Conclusions

Cutting forces indicators may be extremely relevant
- On-line condition monitoring
- RMS value is sufficient to gain valuable knowledge

But...
- Image of tool wear rather than production quality

Roughness indicators may be extremely relevant
- Focus on production quality hence value
- Relevance of standard-recommended indicator questioned
  - Flank wear → wear on nose radius and trailing edge

But...
- No account of other quality indicators
  - Residual stresses, dimensional accuracy, etc.
- Based on sampled quality control
- Complex for on-line use
Thank you for your attention!